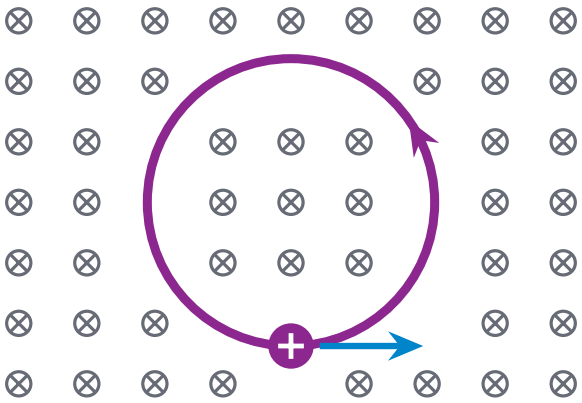
GENERAL PHYSICS 2

ELECTRICITY AND MAGNETISM

WORKBOOK

11 chapters · 170 problems · step-by-step solutions



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How to use this book

- Each chapter opens with a reminder box summarizing the relations the problems rely on. The QR code in the chapter heading links to the lecture video.
- Difficulty: ★☆☆ basic ★★☆ intermediate ★★★ advanced. Each chapter also has a few multiple-choice concept questions.
- The dotted area below each problem is for your own work. Solve first; if stuck, go back to the reminder box and the lecture notes, and look at the solution last.
- All solutions are at the end of the book. The Solution → p. link next to a problem takes you to its solution, and ← Problem p. takes you back. Short answers are in the **ANSWER** box.
- In the figures, electric fields are orange, magnetic fields dark teal, forces red and velocities blue; positive charges are red, negative charges blue.
- Unless stated otherwise, $k = 8.99 \times 10^9\ \mathrm{N\,m^2/C^2}$, $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N\,m^2)}$, $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\,m/A}$ and $e = 1.60 \times 10^{-19}\ \mathrm{C}$; data and results are given to three significant figures.
- The midterm usually covers chapters 01–06 and the final 07–12; choose according to your course.

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CHAPTER 1

ELECTRIC CHARGES AND ELECTRIC FIELD

Coulomb's law	$F = k\dfrac{\lvert q_1 q_2\rvert}{r^2},\ k = \dfrac{1}{4\pi\varepsilon_0}$	dipole moment	$\vec{p} = q\,\vec{d}\ \ (-q \to +q)$
		torque on a dipole	$\vec{\tau} = \vec{p} \times \vec{E}$
electric field	$\vec{E} = \dfrac{\vec{F}}{q_0}$	potential energy	$U = -\vec{p} \cdot \vec{E}$
point charge	$\vec{E} = k\dfrac{q}{r^2}\hat{r}$	charged particle	$\vec{a} = \dfrac{q\vec{E}}{m}$
continuous distribution	$\vec{E} = \displaystyle\int k\frac{dq}{r^2}\hat{r}$		

Unless otherwise stated, neglect the weights of particles. Use $k = 8.99 \times 10^9\ \mathrm{N\,m^2/C^2}$, $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N\,m^2)}$, $e = 1.60 \times 10^{-19}\ \mathrm{C}$, $m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$ and $g = 9.80\ \mathrm{m/s^2}$.

Electric charge and Coulomb's law

1.1 ★☆☆ Solution → p. 109

A neutral conducting sphere on an insulating stand has a negatively charged rod brought near it *without touching*. With the rod held in place, the sphere is briefly connected to ground by a conducting wire and the wire is removed; then the rod is taken away. Which of the following is true of the sphere in the final state?

A) It is positively charged, and its charge is spread uniformly over its surface.

B) It is negatively charged.

C) It is neutral because the rod never touched it.

D) It is positively charged, and its charge stays concentrated on the side where the rod was.

E) When the wire is removed, the excess charge flows back to ground and the sphere is neutral.

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1.2 ★☆☆ Solution → p. 109

Two identical small conducting spheres carry charges $q_1 = +7.20$ nC and $q_2 = -2.40$ nC; their centers are 12.0 cm apart. The spheres behave as point charges.

a. Find the magnitude of the force the spheres exert on each other. Is the force repulsive or attractive?

b. The spheres are touched together and then separated. Find the final charge on each sphere and how many electrons passed from which sphere to which.

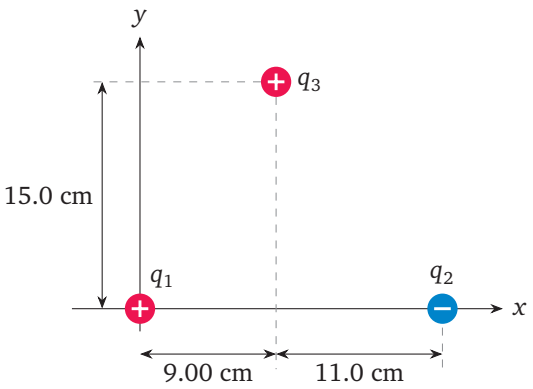
c. If the spheres are placed 12.0 cm apart again, what is the force between them?

1.3 ★★☆ Solution → p. 109

In the xy-plane of the figure, a point charge $q_1 = +2.50\ \mu$C is at the origin, a charge $q_2 = -4.50\ \mu$C is on the x-axis at $x = 20.0$ cm, and a charge $q_3 = +1.50\ \mu$C is at the point (9.00 cm, 15.0 cm).

a. Write the forces that q_1 and q_2 exert on q_3 separately, using unit vectors.

b. Find the magnitude of the net force on q_3 and the angle it makes with the $+x$ axis.



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SOLUTIONS

1 ELECTRIC CHARGES AND ELECTRIC FIELD

1.1

← Problem p. 4

The rod's negative charge repels the free electrons in the sphere and drives them to its far side; the near side is left positive (polarization by induction). When the sphere is connected to ground, the repelled electrons flow into the ground. Because the wire is removed while the rod is still in place, these electrons cannot return and the sphere gains a net *positive* charge. Once the rod is taken away, the charge on the isolated conductor spreads uniformly over the surface by self-repulsion: **A** is correct.

- B: The electrons go to ground; the sphere loses electrons, so it cannot be negative.
- C: Charging by induction needs no contact; the charge comes from or goes to the ground connection.
- D: The positive charge gathers on the rod's side while the rod is nearby; when the rod is removed, that cause disappears.
- E: Once the wire is removed there is no path along which the charge could flow away; charge is conserved.

ANSWER A

1.2

← Problem p. 5

a. From Coulomb's law

$$F_1 = k\frac{|q_1 q_2|}{r^2} = \frac{(8.99\times10^9)(7.20\times10^{-9})(2.40\times10^{-9})}{(0.120)^2} = 1.08\times10^{-5}\ \text{N}.$$

Since the charges have opposite signs, the force is attractive.

b. Total charge is conserved: $q_1 + q_2 = +4.80$ nC. Because the spheres are identical, the charge is shared equally on contact: each ends up with +2.40 nC. The charge of the second sphere has gone from −2.40 nC to +2.40 nC, so electrons carrying 4.80 nC have passed from this sphere to the first:

$$N = \frac{4.80\times10^{-9}}{1.60\times10^{-19}} = 3.00\times10^{10}.$$

c. Now the charges have the same sign and the force is repulsive:

$$F_2 = \frac{(8.99\times10^9)(2.40\times10^{-9})^2}{(0.120)^2} = 3.60\times10^{-6}\ \text{N}.$$

The force drops to 1/3 of its first value and reverses direction.

ANSWER a. 1.08×10^{-5} N, attractive b. each +2.40 nC; 3.00×10^{10} electrons from q_2 to q_1 c. 3.60×10^{-6} N, repulsive

1.3

← Problem p. 5

a. The position of q_3 relative to q_1 is (0.0900, 0.150) m and relative to q_2 it is (−0.110, 0.150) m:

$$r_{13} = \sqrt{0.0900^2 + 0.150^2} = 0.17493\ \text{m},$$
$$r_{23} = \sqrt{0.110^2 + 0.150^2} = 0.18601\ \text{m}.$$

The force from q_1 is repulsive and points from q_1 toward q_3:

$$F_{13} = \frac{(8.99\times10^9)(2.50\times10^{-6})(1.50\times10^{-6})}{0.17493^2} = 1.1017\ \text{N},$$

$$\vec{F}_{13} = 1.1017\left(\frac{0.0900}{0.17493}\hat{\imath} + \frac{0.150}{0.17493}\hat{\jmath}\right) = (0.5668\,\hat{\imath} + 0.9447\,\hat{\jmath})\ \text{N} \approx (0.567\,\hat{\imath} + 0.945\,\hat{\jmath})\ \text{N}.$$

The force from q_2 is attractive and points from q_3 toward q_2:

$$F_{23} = \frac{(8.99\times10^9)(4.50\times10^{-6})(1.50\times10^{-6})}{0.18601^2} = 1.7538\ \text{N},$$

$$\vec{F}_{23} = 1.7538\left(\frac{0.110}{0.18601}\hat{\imath} - \frac{0.150}{0.18601}\hat{\jmath}\right) = (1.0372\,\hat{\imath} - 1.4143\,\hat{\jmath})\ \text{N} \approx (1.04\,\hat{\imath} - 1.41\,\hat{\jmath})\ \text{N}.$$

b. By the superposition principle (using four-digit

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components)

$$\vec{F} = (0.5668 + 1.0372)\,\hat{\imath} + (0.9447 - 1.4143)\,\hat{\jmath}$$
$$= (1.604\,\hat{\imath} - 0.4696\,\hat{\jmath})\ \text{N},$$

$$F = \sqrt{1.604^2 + 0.4696^2} = 1.67\ \text{N},$$
$$\theta = \arctan\frac{0.4696}{1.604} = 16.3^\circ.$$

The net force points 16.3° below the $+x$ axis: the pull of q_2 is stronger and the y component is downward.

ANSWER a. $\vec{F}_{13} = (0.567\,\hat{\imath} + 0.945\,\hat{\jmath})$ N, $\vec{F}_{23} = (1.04\,\hat{\imath} - 1.41\,\hat{\jmath})$ N b. 1.67 N, 16.3° below $+x$

1.4

← Problem p. 6

a. The distance from q_1 to P is $r_1 = \sqrt{0.180^2 + 0.120^2} = 0.2163$ m, and the magnitude of its field is

$$E_1 = \frac{(8.99\times10^9)(8.00\times10^{-9})}{0.2163^2} = 1537\ \text{N/C}.$$

Since q_1 is positive, $\vec{E}_1$ points from q_1 toward P; its components are

$$E_{1x} = E_1\frac{0.180}{0.2163} = (1537)(0.8322) = 1279\ \text{N/C},$$
$$E_{1y} = E_1\frac{0.120}{0.2163} = (1537)(0.5548) = 852.7\ \text{N/C}.$$

Since q_2 is directly below P, its field is along the y direction only. For the y component of the net field to vanish, we need $\vec{E}_2 = -852.7\,\hat{\jmath}$ N/C: because this field points toward q_2, q_2 is *negative*.

$$|q_2| = \frac{E_{1y}\,y^2}{k} = \frac{(852.7)(0.120)^2}{8.99\times10^9} = 1.37\times10^{-9}\ \text{C}.$$

b. Only E_{1x} remains: $\vec{E} = 1.28\times10^3\,\hat{\imath}$ N/C.

c. The force on the electron is opposite to the field:

$$\vec{F} = -e\vec{E} = -(1.60\times10^{-19})(1279)\,\hat{\imath} = -2.05\times10^{-16}\,\hat{\imath}\ \text{N}.$$

ANSWER a. $q_2 = -1.37$ nC b. $1.28\times10^3\,\hat{\imath}$ N/C c. $-2.05\times10^{-16}\,\hat{\imath}$ N

1.5

← Problem p. 6

Field lines start on positive charges and end on negative charges; the number of lines leaving or entering a charge is proportional to the magnitude of the charge.

- 12 lines *leave* q_1: q_1 is positive.
- Of these, 8 *end* on q_2, and no line leaves q_2: q_2 is negative and $|q_2| = \frac{8}{12}|q_1| = \frac{2}{3}|q_1|$.

Hence $q_1/q_2 = -3/2$: **E** is correct. The remaining 4 lines going off to infinity confirm this: the net charge is $q_1 + q_2 = +\frac{1}{3}|q_1|$, which from far away looks like a positive charge with 4 lines.

- A ($\frac{2}{3}$): Both the sign and the ratio are wrong; this is the ratio $|q_2|/|q_1|$.
- B ($\frac{3}{2}$): The magnitude of the ratio is right but the sign is wrong. If the charges had the same sign, the lines would not run from one to the other.
- C ($-\frac{2}{3}$): The sign is right, but the ratio is inverted (it is q_2/q_1).
- D (-1): If the magnitudes were equal, all of the lines of q_1 would end on q_2.

ANSWER E

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